United States Patent Application for

A Method and Apparatus For

A Photomultiplier Power Supply

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Cross Reference to Related Applications

This patent application is related to and claims priority from U.S. Provisional Patent Application No. 60/425,400 filed on November 12, 2002, Entitled "A Method and Apparatus for a Photomultiplier Power Supply" by J. Koudelka and C.

5   Haramboure, which is hereby incorporated herein by reference in its entirety.

Background of the Invention

Field of the Invention

[0001]   The present invention relates generally to the field of photomultiplier

10   power supplies and in particular to a method and apparatus for providing a photomultiplier power supply having a transformer with multiple secondary windings forming cells that can provide voltage ratios to a photomultiplier element in which the ratios can be adjusted by the method of connection to the cell, by the number of turns in the transformer, or by a combination of both.

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Summary of the Related Art

[0002] Power supplies for the provision of power to a photomultiplier tubes is well known in the art.   Photomultipliers are used in a variety of applications, including down hole tools which are deployed in a well bore drilled into the earth. The well

20   bore is typically surrounded by a formation.   In the typical down hole tool application, the tool traverses the well bore and the photomultiplier tube is used to determine counts which Typically, when providing a power supply to a photomultiplier tube for operation, a high voltage from 500 to 3000 volts from the power supply is usually applied across the terminals of the photomultiplier tube. The

25   photomultiplier tube terminals, a cathode (K) **201** and anode (P) **202**, are provided with a proper voltage gradient set up between the photoelectron focusing electrode (F)

203. A dynode is an electrode in an electron tube that functions to produce secondary emission of electrons. Typically dynodes are provided and depending on tube type, an accelerating electrode is also provided. This voltage gradient can be setup by providing a plurality of independent power supplies **200** as shown in **Figure 1**,

5 however, in practice provision of a plurality of power supplies typically not practical.

[0003] Thus, in practice, as shown in **Figure 2**, the inter stage voltage for each electrode is supplied by providing a network of voltage-dividing resistors **205**. In addition, designers will often provide additional Zener diodes **206** connected between

10 the anode and the cathode of the Photomultiplier tube. This typical circuit, as shown in Figure 2 is commonly referred to as a voltage divider circuit or bleeder circuit. The current I_b, flowing through the voltage divider or bleeder circuits shown in **Figures** **2A** and **2B** is approximately equal to the applied voltage V, divided by the sum of resistor values as follows:

15 $I_b = V (R1 + R2 + R3 + R4 + R5 + R6 + R7)$.

[0004] The Zener diodes **206** (D_z) shown in **Figure 2B** are used to maintain the inter stage voltages at constant values for stabilizing the photomultiplier tube operation regardless of the magnitude of the anode current. Capacitors C1, C2 , C3 and C4 can

20 be connected in parallel with the Zener diodes serves to minimize noise generated by the Zener diodes. Zener diode noise becomes significant when the current flowing through the Zener diodes is insufficient. In this case, the added capacitance is required as the Zener diode noise can affect the signal-to-noise ratio of the Photomultiplier tube output.

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[0005] As shown in **Figures 2A** and **2B**, the general technique used for voltage divider or bleeder circuits is to ground **208** the photomultiplier tube anode **202** and apply a large negative voltage to the cathode of the photomultiplier tube. This grounding and negative voltage attachment scheme eliminates the potential voltage difference between the external circuit and the photomultiplier tube anode, facilitating the connection of circuits such as ammeters and current-to-voltage conversion operational amplifiers to the Photomultiplier tube circuit terminals. In this Photomultiplier tube anode-grounding scheme, however, one must be careful when bringing a grounded metal holder, housing or magnetic shield case near the bulb of the Photomultiplier tube, or allowing such an element to make contact with the bulb, which can cause electrons in the photomultiplier tube to strike the inner bulb wall. Such an occurrence may possibly produce glass scintillation, resulting in a significant increase in noise and data errors associated therewith.

[0006] In a photomultiplier tube anode grounding or cathode grounding scheme in either a DC or pulsed operation, when the light level incident on the photomultiplier tube cathode is increased to raise the photomultiplier tube output current, the relationship between the incident light level on the photomultiplier tube and the photomultiplier tube anode current begins to deviate from an ideal linearity relationship at a certain current levels and eventually, the photomultiplier tube output goes into saturation and is no longer linear.

[0007] There are numerous problems associated with all known photomultiplier power supply circuits. These problems are usually encountered in deriving a DC signal output from a photomultiplier tube that is representative of a photomultiplier

tube count or the height of the pulses, which is representative of the energy level. Typically counts are determined using a biasing voltage divider network **300** as shown in **Figure 3**. The current which actually flows through a bleeder resistor such as R7 **302** in the resistor network **304**, for example the current **306** flowing across

5   resistor R7, as shown in **Figure 3**, equals the difference between the bleeder current I_b **308** and the anode current I_p **306** which flows in the opposite direction through the circuit loop of P - D_{y5} - R7 - P. Similarly, for the other bleeder resistors in the resistor network, the actual current flowing through a resistor R1 -Rn is the difference between the bleeder current I_b **308** and the dynode current I_{Dyn} **310** flowing in the

10   opposite direction through the particular bleeder resistor. The anode current and dynode current flow acts to reduce the bleeder current and the accompanying loss associated with the inter stage voltage supplied becomes more significant in the latter dynode stages which must handle the progressively larger dynode currents. Although the dynode current includes additional current components flowing in the same

15   direction as the bleeder current I_b, **308** in the current context, they are of insignificant magnitude for the present discussion.

[0008] For the most part, a reduction of the bleeder currents can be ignored if the anode output is of sufficiently small magnitude. However, when the incident light

20   level is increased and the resultant anode and dynode currents are increased in magnitude, the voltage distribution for each dynode will vary considerably. Because the overall cathode-to-anode voltage is kept relatively constant by the provision of a high-voltage power supply voltage, the loss of the inter stage voltage at the latter stages can be and is redistributed to the previous stages so that there will be an

25   increase in the inter stage voltage.

[0009] The loss of the inter stage voltage by the multiplied electron current appears most significantly between the last dynode and the photomultiplier tube anode, but the voltage applied between the last dynode and the photomultiplier tube anode does not contribute to the secondary emission ratio of the last dynode. Therefore, the shift in the voltage distribution to the earlier stages results in a collective increase in current amplification. If the incident light level is increased further so that the anode current becomes of large magnitude, the secondary-electron collection efficiency of the photomultiplier tube anode degrades as the voltage between the last dynode and the photomultiplier tube anode decreases.

[0010] Typically, two techniques are applied to increase the maximum linear output. First, photomultiplier power supply designers have used lower the bleeder resistor values to increase the bleeder current. Secondly, photomultiplier power supply designers use a Zener diode between the last dynode and the anode and if necessary between the next to last and second to last stage as well. If the photomultiplier power supply bleeder resistors are located close to the photomultiplier tube, the heat emanating from their resistance may raise the photomultiplier tube temperature, leading to an increase in the undesirable dark current and can induce possible fluctuations in the output signal of the photomultiplier power tube. Furthermore, since design technique requires a high-voltage power supply with a large capacity, it is inadvisable to increase the bleeder current more than necessary. To solve the above problems in applications where a high linear photomultiplier tube output is required, individual power supplies may be used in place of the bleeder resistors at the last few stages of a photomultiplier tube power source. With the Zener diode technique for

photomultiplier tube power source design, if the bleeder current becomes insufficient, undesirable Zener diode noise will be generated from the Zener diode, possibly causing detrimental effects on the linearity and associated accuracy output of the photomultiplier tube. Because of this potential inaccuracy in signal from the

5   photomultiplier tube output, it is essential to increase the bleeder current for the photomultiplier tube to an adequate level and connect a ceramic capacitor having an acceptable frequency response in parallel with the Zener diode for absorbing the possible noise in the circuit.

10   [0011] When a photomultiplier tube is pulse-operated, by way of providing a bleeder circuit, such as the circuit shown in **Figure 2A**, the maximum linear output of the photomultiplier tube is limited to a fraction of the bleeder current just as in the case of DC voltage operation. To ameliorate or prevent this problem, decoupling capacitors can be connected to the last few stages. These added decoupling capacitors can also

15   supply the photomultiplier tube with an electric charge during the pulse duration, thereby restraining or mitigating the voltage drop between the last dynode and the anode of the photomultiplier tube, thus resulting in a significant improvement in pulse mode operation linearity. Even with the decoupling capacitors, however, the output of the photomultiplier tube deviates form the desired linear range when the average

20   output current exceeds $1/20^{th}$ to $1/50^{th}$ of the bleeder current. In particular, care is required at high counting rates even when the output peak current is low.

[0012] As discussed above, typical known photomultiplier power supplies typically utilize resistor ladders to provide voltage to a photomultiplier tube. The resistor

25   ladder is undesirable because of their associated high-power consumption and

untenable difficulties in providing some voltage distribution ratios. Moreover,

typically known photomultiplier power supply designs require a complex transformer

construction, making them difficult to manufacture.

5   [0013] As shown in **Figure 4**, a known circuit design is shown in which a Cockcroft-

Walton voltage multiplier circuit **400** is shown in which an array of diodes **401** are

connected in series. Capacitors **402** are connected in series long each side of the

alternate connection points. When a reference voltage V **406** is placed at the input

404, this circuit provides voltage potentials of 2V or 3V and so on at each connection

10   point. Therefore, the power supply circuit shown in **Figure 4** functions much like a

conventional resistive bleeder circuit. The Cockcroft-Walton voltage multiplier

circuit, however, is inordinately complex. Thus, the circuit of **Figure 4**, while known,

requires additional parts and is undesirably difficult to manufacture.

15   [0014] Thus, there is a need for a less complex photomultiplier power supply design

that provides a lower power consumption voltage ratio conversion circuit that also

provides good linearity and is easy to manufacture. Low power consumption is

critical in many environments, such as down hole tools, where power can be limited

and power conservation can be critical. There is also a need for a photomultiplier

20   power supply design that less sensitive to high temperature environments, such as for

use in oil field services operations in a down hole environment such as a wire line or

monitoring while drilling applications which subject equipments and power supplies

to extreme subterranean temperatures.

Summary of the Invention

[0015] The present invention addresses the shortcomings of the related art described above. The present invention provides an apparatus and method for supplying voltage to a photomultiplier tube. The present invention requires less space and fewer components than known photomultiplier tube power supplies discussed above or known to the inventors. In the present invention, approximately one-half of the diodes and capacitors used in known photomultiplier power supply designs are required in the photomultiplier power supply of the present invention. The present invention provides for inherently fixed distribution of voltage ratios between photomultiplier tube terminals. The present invention provides fixed transformer voltage ratios, thereby avoiding the undesirable characteristics of multiplier ladders and resistor ladders used in prior known photomultiplier power supplies. The present invention does not produce a photomultiplier gain shift when a count rate increases as in known designs using resistor ladder because there is not a resistor network used in the design of the present invention. The present invention also consumes very little power. The present invention facilitates the provision of virtually any voltage distribution ratio. The present invention is easy simpler than known designs and therefore is easier to manufacture having a simple transformer construction.

Brief Description of the Figures

[0016] For detailed understanding of the present invention, references should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, wherein:

Figure 1 is a known schematic illustrating photomultiplier tube operation;

Figure 2A and **2B** illustrate a known bleeder circuit;

Figure 3 illustrates a basic known operating circuit for a photomultiplier tube;

Figure 4 is an illustration of a known Cockcroft-Walton voltage multiplier circuit;

Figure 5 is an illustration of a known photomultiplier power supply circuit design;

Figure 6 is an illustration of a known photomultiplier power supply circuit design;

Figure 7 is an illustration of a known photomultiplier power supply circuit design; ,

Figure 8 is an illustration of a preferred embodiment of the present invention;

Figure 9 is an illustration of a preferred embodiment of the present invention;

Figure 10 is an illustration of a preferred embodiment of the present invention; and

Figure 11 is an illustration of a preferred embodiment of the present invention in operation in a high temperature down hole environment.

Detailed Description of a Preferred Embodiment

[0017] Prior known methods and component circuits utilized for providing power to a photomultiplier tube are shown in **Figures 5, 6** and **7**. Turning now to **Figure 5**, a typical resistor divider network **512** utilized in providing power to a photomultiplier tube **510** is shown. This is currently the most commonly used photomultiplier power supply circuit design. The disadvantages of this typical resistor divider network technique, however, are numerous. Utilizing the typical resistor divider network technique shown in **Figure 5**, the photomultiplier tube gain changes at high count rates thereby skewing data and creating errors in conclusions drawn from data measurements taken. In the typical resistor divider network power is lost as heat in the resistors. Finally, the typical resistor divider network circuit requires an external power supply **514**. These factors contribute to the shortcomings of the typical resistor divider network.

[0018] Turning now to **Figure 6**, another known technique is illustrated. In **Figure 6**, dynodes **610** are connected to a multiplier ladder **612**. While the circuit is simpler than the typical resistor divider network circuit of **Figure 5**, there are still significant disadvantages with the circuit design as shown in **Figure 6**. In the circuit of **Figure 6**, the voltage ratio changes from stage to stage, thereby providing a smaller and smaller voltage gradient as the last (most negative) stage is reached. Thus, using the circuit of **Figure 6**, it is very difficult to implement ratios other than 1:1, 1:2 or 1:3. Additionally, compared to the present invention, the diodes and capacitors **614** of the circuit of **Figure 6** are almost four times in quantity, as are the losses associated with those elements, especially at high temperatures. The high temperature factor is exacerbated when using a photomultiplier **100** and photomultiplier power supply**101**

in a high temperature environment such as when providing power in a down hole tool 102 deployed via a drill string or wire line 105 for determining the characteristics of a well bore 103 drilled in the earth 106, or a formation 104 surrounding a well bore when used in a down hole tool environment as shown in **Figure 11.** The use of

5 photomultiplier in such tool is well known in the art.

[0019] Turning now to **Figure 7,** another known photomultiplier **700** power supply circuit design is illustrated, wherein the transformer design is very complex and there is a net DC field present in the transformer core. Note that in **Figure 7,** there are 11

10 coils **710** versus the 5 coils of the preferred embodiment of the present invention as shown in **Figure 9.** Additionally, there essentially twice as many dynodes **712** necessary for the known design of **Figure 7,** versus the preferred embodiment of the present invention as shown in **Figure 9,** discussed below.

15 [0020] The power supply of the present invention comprises a series of basic cells to which the photomultiplier tube terminals connect. Turning now to **Figure 8,** the preferred embodiment of the present invention comprises a plurality of secondary transformer windings **800.** These secondary windings **800** can have all the same number of turns/windings or the number of turns/windings may differ from each other

20 as desired by the photomultiplier tube application and design.

[0021] In a preferred embodiment, two diodes **810, 812** and two capacitors **814, 816** are connected to each transformer winding as shown in **Figure 8.** The positive terminal of a given cell connects to the negative terminal of the following cell. The

25 negative terminal of the first cell is connected to the photo cathode, the first dynode to

the center tap **818** (CT), and the second dynode to the positive terminal. The connection sequence is then repeated until the resistor connected in series with the anode terminal is reached. Any unused terminal in the last cell is left unconnected. To change the voltage ratio between tube elements, any dynode connection can be moved from the terminal CT to the positive terminal, the winding voltage changed, or a combination of both implemented.

[0022] Turning now to **Figure 9**, a preferred embodiment of the present invention is shown in which all windings are identical, thus all tube terminals have the same voltage gradient. Turning now to **Figure 10**, if all windings are equal, the first dynode has twice the voltage gradient. If the winding ratio is 1.5:1, then the gradient will be 3:1 instead.

[0023] In another embodiment of the present invention, the method of the present invention is implemented as a set computer executable of instructions on a computer readable medium, comprising ROM, RAM, CD ROM, Flash or any other computer readable medium, now known or unknown that when executed cause a computer to implement the method of the present invention.

[0024] While the foregoing disclosure is directed to the preferred embodiments of the invention various modifications will be apparent to those skilled in the art. It is intended that all variations within the scope of the appended claims be embraced by the foregoing disclosure. Examples of the more important features of the invention have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be

appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto.